A method for assessing the damping characteristics of periodontal tissues: Goals and limitations

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The Periotest method, an objective, noninvasive clinical diagnostic method, is a dynamic procedure that measures the resistance of the periodontium to a defined impact load. It has been reported that Periotest values depend to some extent on tooth mobility, but mainly on the damping characteristics of the periodontium. Nevertheless, the real clinical meaning of the measurements and some important limitations of the Periotest measuring principle still seem to be poorly understood. In the present study, the relationship between damping characteristics of periodontal tissues and tooth mobility was investigated. The best correlations between tooth deflection and Periotest values were found for teeth showing a certain degree of clinical mobility (R^2 from .79 to .91). Nevertheless, this correlation was clearly lower when only healthy subjects were examined (R^2 from .43 to .54). The better correlation found for forces greater than 1.0 N indicates that the damping characteristics assessed with the Periotest method are related to secondary tooth movement. The Periotest methodology, measuring principle, and limitations are critically reviewed. (Quintessence Int 1995;26:191–197.)

Introduction

Tooth mobility has attracted the interest of investigators for both clinical and scientific reasons. The mechanisms of tooth support have received a considerable amount of interest and a number of conclusions have been drawn from observations in both animal and human studies.[1] Like the masticatory system, tooth mobility is a dynamic process. The stability of a tooth is dependent on the resistance of its supporting structures

and the character of the forces directed against it. Tooth mobility is mainly related to the hydrodynamic and biophysical properties of the periodontal ligament with the fiber bundles embedded in two mineralized periodontal tissues: the root cementum and the jawbone. It can be classified as either physiologic or pathologic mobility,[2] self-limited, or progressive.[3]

The investigator who wants to assess the degree of tooth mobility faces a complex problem. This is evident from the number and diversity of methods reported.[4–11] To obtain a complete knowledge of tooth mobility, three-dimensional measurements are required. Such measurements are probably too complicated for practical purposes. Most investigators have confined their efforts to study tooth mobility to one single direction, either buccolingual[4] or axial.[5] The method most commonly used to detect tooth mobility is deflection.[3] With this technique, teeth are evaluated according to the ease and extent of their movement. They are held firmly between two instruments, two fingers, or one of each and are moved back and forth. Although this approach seems to be very reproducible,[12] the need for an objective assessment is evident. Some methods, such as the

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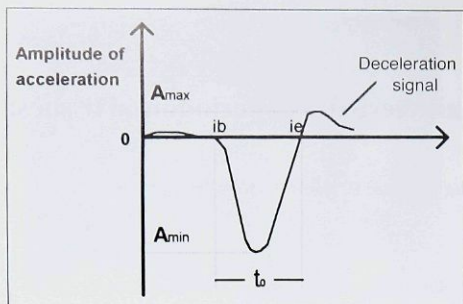
Fig 1   Schematic representation of the deceleration signal.[34] Time (t_0) from the beginning of the impact (ib) until the zero crossing (acceleration zero) or end of the impact (ie). Therefore, t_0 represents the contact time of the tapping head with the tooth.[34] Minimum acceleration amplitude (A_{min}); (A_{max}) maximum acceleration amplitude.

Periodontometer developed by Mühlemann, are too complex and time consuming for use in daily practice.[13]

Recently, several clinical studies have used an objective, noninvasive clinical diagnostic method for the assessment of tooth[14-16] and even implant[17-23] stability, the Periotest method (Siemens). It is an objective, dynamic measuring procedure that assess the resistance of the periodontium to a defined impact load. According to Schulte and Lukas,[24] "the Periotest value depends to some extent on tooth mobility, but mainly on the damping characteristics of the periodontium." Despite its increasing use in clinical and experimental trials, the real meaning of the measurements and the limitations of the Periotest measuring principle seem to be poorly understood. The aim of the present study was to determine the relationship between damping characteristics of periodontal tissues and tooth mobility. In addition, the Periotest methodology, measuring principle, and limitations will be critically reviewed.

Method and materials

Patients and subjects

The sample material comprised 58 maxillary anterior teeth from 11 periodontally healthy subjects (5 women, aged 20 to 37 years; mean = 2.49 years; SD = 2.3 years), and 54 maxillary anterior teeth from 11 patients (seven women, aged 21 to 54 years; mean = 41.7 years; SD = 5.9 years) who were seeking periodontal treatment and clinically showed some degree of tooth mobility measured by the method described by Miller.[25] Ten teeth exhibited degree I mobility, 27 exhibited degree II mobility, and 17 exhibited degree III mobility.

Assessment of tooth mobility

Tooth deflection was measured by means of the Mühlemann Periodontometer.[4] The measuring gauge rod was brought into contact with the labial surface of the tooth to be measured. To make the gauge independent of the movements of the patient's head, it was attached to a special impression tray that was fixed to the premolars and molars by means of plaster. Once the plaster was fixed, the tooth to be examined was loaded horizontally (at a distance of 2 mm from the incisal edge) with a dynamometer with a tip coated with diamonds to increase friction. The tooth was thus gently brought from its rest position into a labial position by a certain force: 0.5 N, 1.0 N, 2.0 N, and 5.0 N. The gauge dial registered the distance from rest to labial position in hundredths of a millimeter. On sudden removal of the force, the crown returned almost to its original rest position within 2 seconds. Subsequently, the tooth was similarly moved from the new rest position in a palatal direction. The total distance from extreme labial to extreme palatal position is called *total excursion*.

Assessment of damping characteristics

Damping characteristics of the periodontium were assessed by means of the Periotest device, which consists of a handpiece connected by a cable to a unit that controls functions and analyzes measurements. In the interior of the handpiece, a metal rod of 8 g mass is accelerated until it reaches its nominal speed (0.2 m/s). Before the rod comes out of the handpiece, the propulsion electromagnetic field is switched off. The velocity of the rod remains constant, maintained by compensation for the influence of friction and gravitation, until it contacts the tooth. The distance between the handpiece and the tooth under percussion can vary within a range of 4 mm without affecting the results of the measurement. On impact, the tooth is slightly deflected and the tapping head is decelerated (Fig 1). Then the tapping head is automatically drawn back into the starting position at the rear stop. The deceleration of the rod on impact with the tooth is measured by an accelerometer, while a chronometer measures the time in which this contact takes place (Fig 1). The faster the de-

celeration, the higher the damping of the periodontium. While reaction forces bring the tooth back to its original position, the rod is again accelerated forward, obtaining, in a period of 4 seconds, 16 impacts with the tooth.

A microcomputer in the Periotest unit checks the validity of the measuring signal and rejects faulty ones, signaling them acoustically to the user. Simultaneously, faulty manipulation of the handpiece is also acoustically indicated. (The signal is rejected if the inclination of the handpiece during measurement is greater than ± 11 degrees). Thus the operator can, when necessary, correct the inclination of the handpiece.

The contact time (CT) between tooth and tapping head is the signal used for analysis by the Periotest system. This value fluctuates within a range from 0.266 to 2.27 milliseconds. However, rather than using the measured CTs in milliseconds, the Periotest values (PTVs) are based on a numerical scale from −8 to +50 (see Discussion). Both Periodontometry and Periotest measurements were taken at the same session by the same two examiners.

Periotest measurements were performed twice on every examined tooth, with the methodology described earlier.[27] The handpiece was held in a horizontal position with the start button on top. An orthoradial percussion just in the middle of the buccal tooth surface and perpendicular to the labial surface was done twice for each tooth. The measurement value was given by the synthetic computer voice and was also indicated digitally. The instrumental and operating error of the Periotest equipment is ±1 unit for the anterior teeth.[27] An average of both PTVs obtained was calculated, and half scores could be used.

Statistical analysis

For the statistical analysis, the data were divided in two groups: the healthy subjects and the periodontal patients who showed a certain degree of clinical tooth mobility measured by means of the Miller method.[25] The analysis was done with the excursions (periodontometry values) obtained with five different forces (0.5 N, 1.0 N, 2.0 N, and 5.0 N) when they were applied to the different directions, labial and palatal, and also to the total excursion. For both groups, linear regression equations were fitted with PTVs as the x variable and the Periodontometry values as the y variable. For the group of periodontal patients, the analysis was also repeated with the CT as variable instead of the PTVs. This was calculated with the corresponding formulas

(see Discussion). Graphs were built by using the coefficient of determination (R^2) of the linear regression equations obtained in the three different analyses. The coefficient of correlation corresponds to the square root of R^2.

Results

The coefficient of determination (R^2) of the regression equations obtained in the three analyses are graphically displayed in Figs 2 to 4. The regression equations with the total excursion always had the best R^2, followed by the excursions in the labial and then palatal directions.

Considering only the total excursion, when forces of 0.5 N were applied to healthy teeth, R^2 was only .46. This coefficient reached a value of .67 among periodontal patients, and increased to .79 when CTs were used as the variable, instead of PTVs, to avoid the effect of the different formulas (see Discussion). For forces of 1.0 N applied to healthy teeth, R^2 reached a value of just .50. However, among periodontal patients, it reached a value of .64, and even .75 when CTs were used for the analysis instead PTVs. Forces of 2.0 N applied to healthy teeth reached an R^2 of only .43. Among periodontal patients, however, this coefficient increased to .77, and even to .90 when CTs were used as the variable. Finally, forces of 5.0 N applied to healthy teeth had an R^2 of .54, and the same forces applied to periodontal patients reached an R^2 of .82. Even more, when CTs were used for the analysis, this coefficient increased to .91.

In the group of healthy subjects, the best R^2 ranged from .43 to .54. In the group of periodontal patients, R^2 values increased to a range of .64 to .82. When the CTs were used for the analysis, this parameter reached values ranging from .79 to .91.

Discussion

The principle of most methods to assess tooth mobility is to apply the force to some suitable area of the tooth surface, usually near the incisal edge, and to measure the resulting displacement by some mechanical or electronic device. Different methods, which vary in rate, frequency, duration, and amount of applied force, do not necessarily depict the same properties of the periodontium. Initial tooth mobility, defined as tooth displacement under loading of less than 1.0 N, has been suggested to be related to the fibers and vascular components of the periodontium.[28] Distortion of the alveo-

Tooth deflection vs PTV (healthy subjects)

☐ Palatal (P) ☐ Labial (L) ▨ Total (T)

Coefficient of determination

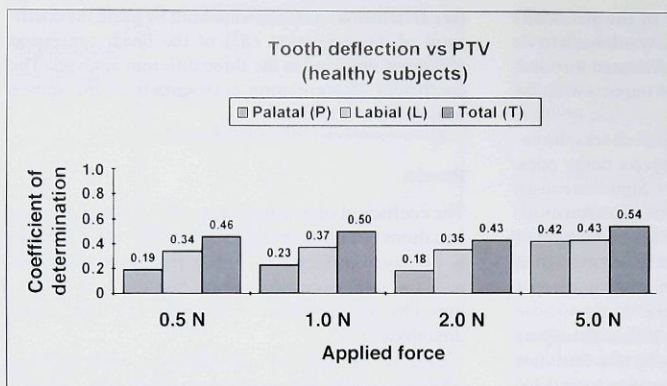| Applied force	P	L	T
0.5 N	0.19	0.34	0.46
1.0 N	0.23	0.37	0.50
2.0 N	0.18	0.35	0.43
5.0 N	0.42	0.43	0.54

Fig 2 Coefficient of determination (R^2) of all regression equations, when tooth deflection and PTV of periodontally healthy subjects are correlated.

Tooth deflection vs PTV (periodontal patients)

☐ Palatal (P) ☐ Labial (L) ▨ Total (T)

Coefficient of determination

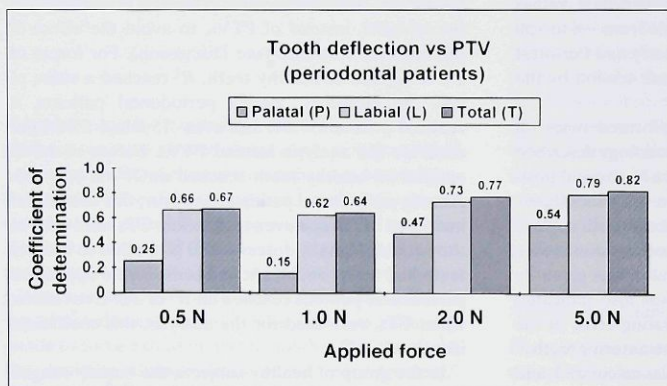| Applied force	P	L	T
0.5 N	0.25	0.66	0.67
1.0 N	0.15	0.62	0.64
2.0 N	0.47	0.73	0.77
5.0 N	0.54	0.79	0.82

Fig 3 Coefficient of determination (R^2) of all regression equations, when tooth deflection and PTV of periodontally compromised patients are correlated.
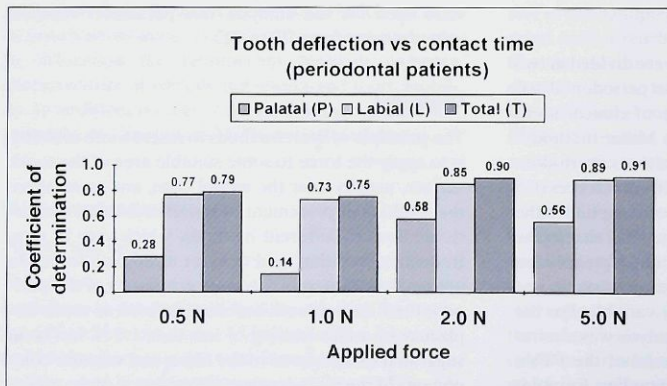
Tooth deflection vs contact time (periodontal patients)

☐ Palatal (P) ☐ Labial (L) ▨ Total (T)

Coefficient of determination

Applied force	P	L	T
0.5 N	0.28	0.77	0.79
1.0 N	0.14	0.73	0.75
2.0 N	0.58	0.85	0.90
5.0 N	0.56	0.89	0.91

Fig 4 Coefficient of determination (R^2) of all the regression equations, when tooth deflection and CT of periodontally compromised patients are correlated.

lar plate (secondary tooth movement) has been demonstrated at application of forces exceeding 1.0 N.[4]

Oikarinen et al[29] measured the total tooth deflection under a predetermined 1.0-N loading force (using Mühlemann's Periodontometer) and the PTVs of maxillary incisors in five healthy patients. They found a correlation coefficient of .66 between both methods. On the other hand, Schulte et al[27] measured the total tooth deflection, applying 2-N, 3-N, and 4-N forces (Körber[6]), as well as the PTVs of maxillary central incisors of 13 patients (all of whom showed some degree of marginal bone loss) and four healthy subjects. They found a better correlation coefficient (.79) when a force of 4 N was used to deflect the teeth.

The present data confirmed the results of both above-mentioned studies. A better correlation coefficient was found when the total tooth deflection was used as the parameter for comparison with PTVs. The correlation was not improved by concentrating on either the labial or palatal displacement alone. The better correlation for forces greater than 1.0 N indicates that the damping characteristics assessed with the Periotest method are also related to secondary tooth movement.

Based on these data and on the published literature, it is evident that PTVs correlate highly with tooth mobility assessed by means of Mühlemann's Periodontometer. Nevertheless, this correlation was clearly lower when only healthy subjects were examined.[29] Furthermore, the present results indicated that the best correlations between tooth deflection and PTVs were found for teeth showing a certain degree of clinical tooth mobility (see Figs 3 and 4). The reason for this fact can be found in the methodology described for the use of the Periotest method. According to the methodology reported for teeth,[24] an orthoradial percussion must be done always just in the middle of the buccal surface of the anatomic crown and perpendicular to the labial surface. This methodology has shown to be highly reproducible on healthy teeth,[30] but seems to face important limitations when damping characteristics of teeth with mobility caused by periodontal breakdown are to be measured.

According to Körber,[6] at high speeds of loading, the "resistance" of periodontal ligament increases, especially that of the soft tissues: above a certain loading rate and under certain impulse patterns, the soft ligament becomes "hard" and the tooth is no longer mobile in the alveolar socket. To explain this phenomena, it must be remembered that many of the vessels run for several millimeters within the vascular network of the periodontium,[31] and probably blood and interstitial

fluids are squeezed from the vessels with static or semistatic acting (1 second or more) thrusts to the tooth. In contrast to this, dynamic methods (such as the Periotest system) apply repeated and especially rapid loadings (fractions of a second) to the tooth, and there is insufficient time to force interstitial or vascular fluids out of the periodontium.[5]

These repeated and rapid loadings applied to a tooth are likely to generate a considerable amount of energy (to be absorbed by the tooth and/or by the periodontium), and it would be reasonable to assume that this is normally dissipated as heat by the periodontal fluids and the active circulatory system.

Qualitative factors, such as hormonal changes,[32] vasoconstrictors,[33] and first stages of periodontitis,[8] can, without affecting the marginal bone level, alter mainly the hydrodynamic damping system. In this case, the energy might not be dissipated as efficiently as by the healthy periodontium, and part of it would be absorbed in terms of tooth displacement. Subsequently, the CT will differ by fractions of a millisecond and the PTV will increase. On the other hand, when the tooth undergoes marginal bone loss as a consequence of a chronic inflammation, it may lead to some tooth mobility, mainly as a result of quantitative changes of the supporting structures. In this case, these repeated and rapid loadings, applied to the same point on the anatomic crown as on the healthy tooth, would generate an amount of energy that would be immediately dissipated by means of the tooth displacement. It is evident that, in these cases, the Periotest is not solely measuring damping characteristics of the periodontium, but also tooth deflection. Hence, the greater the tooth mobility, the higher its influence on the PTV.

This phenomenon results not only because of the tooth mobility caused by periodontal breakdown, but also because on those teeth, forces are applied at a greater distance from the fulcrum than in the earlier clinical situation. Therefore, when teeth undergo this type of condition, it is impossible to use the Periotest method to detect or distinguish the effects of qualitative factors (mentioned above) or even to assess the damping characteristics of a reduced but healthy periodontium that has reached a certain degree of tooth mobility. In other words, the methodology described for teeth seems to be inappropriate for assessing the damping characteristics of the periodontium when mobility caused by marginal bone loss is present. Further research should be aimed to develop a modified routine that must consider other parameters in relation with the marginal bone loss.
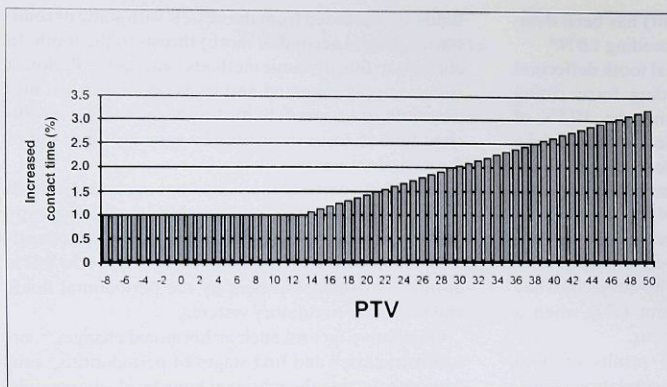
Fig 5 Percentage of rise in CT from one PTV unit to the following one, along the scale. Because the formula for the lower range (PTV ≤ 13) is linear and the one for the upper range is quadratic, the rise is not the same everywhere in the scale from −8 until +50. From −8 until +13, the CT increases 0.02 millisecond by each PTV. This means 1% of the total rise (2.004 milliseconds), by each PTV. But from +14 to +50, this 1% successively grows an additional 0.0012 millisecond (0.06% of the total rise) by each PTV. Therefore, in this part of the scale, the CT increases 0.02 + (PTV − 13) × 0.0012 milliseconds by each PTV.

In addition, the Periotest method faces another important limitation, the clinical interpretation of measurements. As was mentioned earlier, rather than using the measured CTs in milliseconds, PTVs are based on a numerical scale from −8 to +50. This scale is calculated by means of two different formulas designed to produce a convenient range of values:

1. Formula for PTV ≤ 13:

$$PTV = \frac{contact\ time}{0.02\ ms} - 21.3$$

2. Formula for PTV > 13:

$$PTV = 10 \times \sqrt{\frac{contact\ time}{0.06\ ms} - 8.493} - 4.17$$

In the upper range (PTV > 13), the formula is quadratic, and in the lower range (PTV ≤ 13), the formula is linear. Thus, if the CT from PTV − 8 (0.266 milliseconds) to PTV +50 (2.27 milliseconds) rises 2.004 ms (total rise), this rise is not proportional everywhere in the scale (Fig 5).

From PTV −8 until PTV +13, the CT increases 0.02 milliseconds from one PTV to the following one—this represents 1% of the total rise by each PTV (Fig 5). From PTV +14 until PTV +50, however, the rise in CT from one PTV to the following PTV is not the same 1%. It progressively grows an additional 0.0012 milliseconds (0.06% of the total rise) by each PTV. Therefore, the rise in CT will be 0.02 + (PTV −13) × 0.0012.

To avoid this limitation, the group of periodontal patients (in whom PTVs along the whole scale are found) was analyzed according to the CTs instead of the PTVs. With this analysis, the results showed even higher R^2 values (see Figs 3 and 4). This result may be interpreted as the Periotest method's measurement of damping characteristics of the periodontium, but it is highly influenced by tooth mobility. Moreover, when mobility is clinically detectable by means of the Miller method,[25] the PTVs correlate highly with it, and damping characteristics of the periodontium are doubly measured.

From all this it may be concluded that the Periotest device decreases in sensitivity as the PTV increases from +13 until +50. The clinical meaning of a rise in one PTV unit is not the same along the whole scale. This fact must be considered when following up patients and in longitudinal studies.

According to the published literature,[24,26,34,35] the Periotest method was developed to produce a reproducible percussive force to apply defined and reproducible impacts. However, there are no detailed data concerning the amount of force that the instrument produces. In a preliminary in vitro study (not described in the publication), Teerlinck et al[19] found that the peak value of the force delivered by the rod varied between 12 and 18 N for PTVs of +2 to −4, respectively. On the other hand, Chavez et al[21] found, in an in vitro project, that the load the Periotest handpiece rod applies to the object being tested is approximately 5 N (the PTV recorded during the load test was −7).

A distinction should be made between tooth mobility and damping characteristics of the periodontium. Based on the published information, the Periotest method has proved to be objective and highly reproducible for measurement of damping characteristics of healthy teeth[30] and the bone-implant interface.[23] Nevertheless, both clinician and researcher should be aware and take in account the limitations of this device. This will lead to a more reasonable, critical, and accurate use of the device as well as a better interpretation of the values.

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